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APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) IN BIOTECHNOLOGY AND MEDICINE

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Abstract: *Artificial Intelligence (AI) is the creation of intelligent systems that perform tasks requiring human intelligence, such as learning, problem-solving, and decision-making. Humans and AI systems work together. This study summarizes the potential of AI and its application in medicine, agriculture, and biology-based industries. AI in agriculture provides solutions for food security by adapting agricultural management in a changing climate. Extreme temperatures can reduce wheat yields by 6% per °C. Digitalization in agriculture improves the collection and recording of data on soil health. A reservoir of genetic resources for crops and soil is provided in biodiversity ecosystems, which are key for*

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the diversity of micronutrients. Traditional medicine is widely used by 60% of the world's population, and it originates from medicinal plants from wild populations. As the field of AI evolves with more trained algorithms, the potential for its application in epidemiology, studying host-pathogen interactions, and drug design expands. AI relies on digital technology and is applied in several areas of pharmacy, adaptive medicine, gene editing (CRISPR: a new revolution in genetic technology), radiography, image processing, and drug management. AI is used to identify patterns of new drugs, optimize existing therapies, and use an individual's genomic data and other types of health data to develop personalized treatment plans tailored to their specific needs. It is also used for data analysis, e.g., electronic health records and wearable devices, to identify patterns and correlations that may indicate the presence of a particular disease, helping to improve diagnosis accuracy and enable earlier intervention to prevent disease progression, as well as for medical imaging to identify abnormalities and diagnose diseases.

Keywords: *Artificial Intelligence, medicine, biotechnology, digitalization, data analysis.*

INTRODUCTION

Artificial Intelligence (AI) offers transformational potential in all sectors and industries, ranging from supply chain management (Chi et al., 2020; Nissen and Sengupta, 2006) to medicine (Ali et al., 2018; Cepolina and Muscolo, 2014; Mettler et al., 2017; Vang et al., 2015) and automotive (Lugano, 2017). AI provides opportunities to reinvent business models (Duan et al., 2019), change the future of work (Schvartz et al., 2019), improve performance (Wilson, Daugherty, 2018), and enhance human capabilities (Dwivedi et al., 2021; Collins et al., 2021). AI-based tools and applications help automate complex production processes, meeting the rapidly growing demand for pharmaceuticals, industrial-use chemicals, food, and other raw materials based on research of complex

biological systems. Machine learning (ML), a subset of AI, helps predict outcomes by executing vast permutations and combinations of data sets available for drug molecules to determine the best combination without relying on traditional manual methods in the laboratory. Although traditional model-based methods are still useful for analyzing biological data, they lack the capability to leverage the vast amounts of available data, or even big data, to discover insights, predict data behavior, and understand complex relationships between obtained data. Extensive use of big data is becoming increasingly important in biotechnology and bioinformatics as it continues to grow and become available for scientists to analyze worldwide. There are multiple reasons for the rise in interest in artificial intelligence in recent years (Von Krogh, 2018). In the past few decades, there have been tremendous advancements in some of the foundational methods of artificial intelligence (conventional neural networks), many of which have become open-source and therefore available to everyone. AI requires extensive and sophisticated computing, so the decreasing costs of computer hardware and dedicated AI chip designs are more appealing to organizations. The emergence of the COVID-19 coronavirus increased interest in artificial intelligence as people become accustomed to the reduced human element at all levels of society and the increased use of automation (Coombs, 2020; Sipior, 2020). AI and deep neural network designs can efficiently analyze genomic data to determine the genetic basis of traits and uncover genetic markers associated with specific traits. AI can help decipher complex relationships between different pieces of information hidden in data to extract meaningful results for interpretation and practical implementation. AI attracts significant attention due to its capabilities for faster processing of massive data and extracting meaningful information. AI-based digital image processing, drug design, and virtual drug trials could transform medical sciences in the near future (Ghaffar et al., 2023). This study highlights how artificial intelligence and its components can be used in the medical, agricultural, and bio-based industrial sectors to make human life more sustainable.

ARTIFICIAL INTELLIGENCE (AI) IN MEDICAL SCIENCES

A wide range of medical diagnoses is based on the analysis of disease images obtained using high-tech digital devices. The application of artificial intelligence (AI) in evaluating medical images has led to accurate assessments being performed automatically, which in turn has reduced the burden on doctors, minimized errors and diagnosis time, and improved performance in predicting and detecting various diseases. AI techniques based on medical image processing are an essential area of research that uses advanced computer algorithms for prediction, diagnosis, and treatment planning, resulting in a significant impact on decision-making procedures. Machine learning (ML) and deep learning (DL) as advanced AI techniques are two main subfields applied in the healthcare system for diagnosing diseases, drug discovery, and identifying risk factors for patients (Ghaffar et al., 2023). Advances in medical science and biotechnology have opened new avenues for the development of drugs and antibiotics. AI has enormous potential for broad application in the pharmaceutical industry. Using AI, new therapeutic molecules can be discovered based on known target structures. The branch of artificial intelligence known as ML is commonly used in disease diagnostics as it uses diagnostic test results to improve the accuracy of outcomes. AI enables researchers to manage the prediction and analysis of diagnoses, patient responses to treatment, and patient survival. This includes quantitative and predictive epidemiology, precision medicine, and host-pathogen interactions. AI can aid in the detection and diagnosis of diseases and make computer code more understandable for non-technical experts. Predictive epidemiology, individually-based precision medicine, and analysis of host-pathogen interactions are examples of research areas that could benefit from breakthroughs in machine learning and deep learning. These approaches help in diagnosing diseases and identifying individual cases, making more accurate predictions with fewer errors, faster decision-making, and better risk analysis. The increasing number of tissue biomarkers and the complexity of their evaluations significantly promote the use of AI-based techniques. These AI-based biomarkers

assist doctors in diagnostics. More realistic models of complex socio-biological systems are achievable due to knowledge representation and reasoning modeling. ML-based methods can also be used to improve the efficiency and reliability of epidemiological models. Advances in ML have helped develop ten cellular parameter algorithmic models based on programs that can accurately distinguish benign from malignant tumors (Ghaffar et al., 2023).

It is important to consider individual differences in genetics, ecology, and lifestyle in precision medicine. Doctors recognize that an individual's metabolism, physical and physiological characteristics, and genome structure affect how their body responds to drugs. Despite this, a blanket approach that treats all patients with the same drug, regardless of their different conditions, is still used. Thanks to advances in artificial intelligence, a new era of personalized medicine is developing, where pharmaceutical products are tailored to the needs and adaptability of the organism. Although the transition may seem straightforward, it involves a significant amount of data collection, processing, maintenance, and clarification of the obtained data. Millions of analyses and predictions will be involved in the process to identify the best therapeutic approaches for molecules for a specific case. Using this strategy, doctors and clinicians can better predict which treatment and prevention strategies will be most effective for specific patient groups. Researchers could use AI in studies of DNA, RNA, and proteins to better visualize the effects of drug doses on living tissue over time and reorganize signaling networks during therapy. Based on artificial intelligence, IBM Watson helps create an appropriate treatment plan for a patient depending on their medical history and personal data, including genomic structure. An AI-based personalized medicine system will not only reduce treatment costs but also minimize drug side effects in patients. In addition to saving time and improving patient care, AI can also simplify gene editing, radiography, and drug management planning procedures. Electronic health records (EHRs) can be enhanced with evidence-based clinical decision support systems. Machine learning (ML) is based on learning methods and can be divided into three categories: supervised (classification, regression,

and composition), unsupervised (association, clustering, and dimensionality), and reinforcement learning (Wu et al., 2021), Figure 1. AI includes enormous processing capacity (supercomputers), algorithms that can learn at phenomenal speeds (deep learning), and a new strategy that leverages the cognitive talents of the doctors themselves.

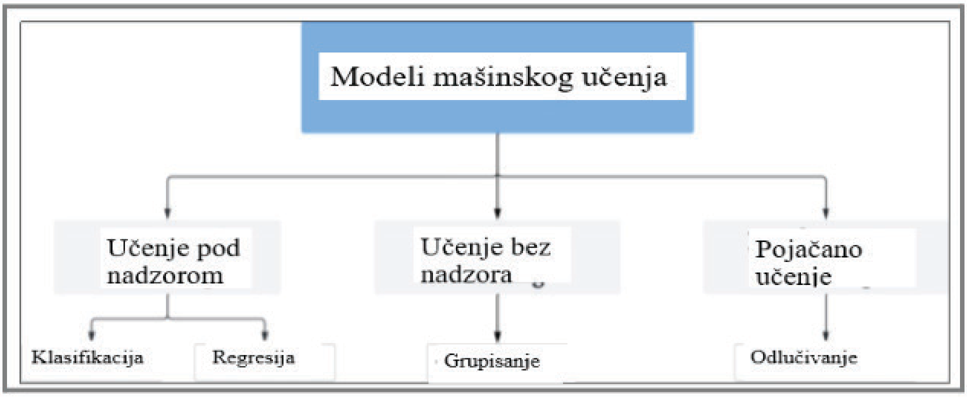

Figure 1. Machine Learning models and main algorithms

This technique contributes to the development of innovative theoretical models of disease pathophysiology and can help predict the major adverse effects of prolonged drug use. It has been found that an AI-based approach is very useful for the early identification, diagnosis, prognosis, and treatment of myopia. In cardiology, dermatology, and oncology, deep learning algorithms show good results in disease diagnostics. Computer algorithms can detect breast cancer metastasis in biopsies of positioned lymph nodes on whole-slide images with an accuracy rate of over 91%, which increased to 99.5% when supplemented with physician data. One proven application of artificial intelligence in risk analysis is the diagnosis of heart disease through cardiovascular imaging. It includes automated monitoring of all deviations from normal conditions based on image processing, myocardial function, and detection and analysis of coronary atherosclerotic plaques (Ghaffar et al., 2023). There are several variables that can be effectively analyzed using artificial intelligence, such as determining conditions that are resistant to certain antibiotics but not others. Such analysis

can support doctors and significantly reduce unnecessary testing and healthcare costs.

One of the most important subfields of AI is machine learning (ML), with essential subfields being neural networks (NN) and deep learning (DL) (Figure 2).

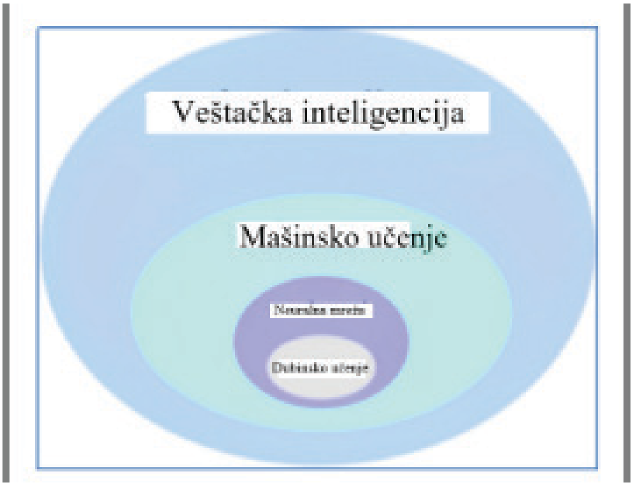

Figure 2. Relationship between AI, ML, NN, and DL approaches

It is important to emphasize the importance of combining these algorithms with medical expertise. New pharmaceutical compounds can be discovered through data analysis using artificial intelligence, reducing the need for clinical trials, and allowing drugs to reach the market faster without compromising their safety. The onset of genetically predisposed diseases may be predicted significantly earlier with the help of AI. Patients will also be able to prevent and treat certain hereditary diseases. One application of artificial intelligence in the pharmaceutical industry is the use of “open target,” a relatively new scientific strategic effort to explore the relationship between drug targets and diseases, as well as how certain genes are related to diseases. SPIDER is another AI technique designed to determine the role of natural products in drug discovery. Quantitative structure-activity relationship (QSAR) studies are particularly useful in creating new effective drugs in a very short period using computer simulation tools. The QSAR model, based on the radial basis function (RBF) artificial neural network (ANN) model, trained using the particle swarm optimization (PSO)

technique, was used in a study to predict pKa values for 74 different types of drugs. Natural language processing (NLP), ML, and robotic process automation are clearly three key areas of advancement for AI in the field of medicine. NLP has recently been used to improve colonoscopy analysis, enhancing the accurate detection of adenomas and polyps. Additionally, the ML approach can be used to predict diseases such as atrial fibrillation and urinary tract infections in certain patient groups using models like the support vector machine (SVM) based on the clinical characteristics of the diseases. Similar initiatives have been used to improve the prognosis of heart disease using heart murmur detection technology. The Food and Drug Administration (FDA) has already approved up to 29 AI-based medical devices and algorithms in various medical science fields (Ghaffar et al., 2023).

The first AI-based model approved by the FDA in the healthcare sector was a diagnostic model based on an autonomous AI system. The model was trained with a diverse set of data samples consisting of individuals of different ages, races, and genders, minimizing the chances of errors across different groups. Several randomized clinical trials (RCTs) have also been conducted to test the efficacy and safety of AI and ML models in clinical practice. In an RCT, the impact of an automated polyp identification algorithm based on deep learning on polyp detection accuracy and adenoma detection rate (ADR) was assessed. In this RCT, consecutive patients were randomly assigned to undergo colonoscopy with or without the aid of an automated polyp identification model, which provided simultaneous optical results and audible alerts upon polyp detection. The results obtained from patients who underwent the AI-based automated detection system outperformed the control groups in ADR and the average number of adenomas and polyps detected per colonoscopy. This automated technology could thus be relevant in treatment regimes and routine practices for improved colon polyp identification due to its high sensitivity, accuracy, and stable results. The introduction of AI systems in medical decision-making has also resulted in cost-effectiveness in overall medical treatment. The pharmaceutical industry will

more comprehensively clarify very complex genetic information with improved AI and ML skills. Clearly, when integrated with ML and NLP, robotic process automation has significant applications and the potential to reshape medical science in the near future. Despite the significant progress made, much more research is needed before AI-based therapy becomes a reality (Lam et al., 2022).

Traditional medicine is widely used by 60% of the world's population, and it originates from medicinal plants from wild populations and cultivation. AI is used in medicine in drug discovery and development: AI is used to identify patterns that help in identifying new drugs and drug targets, as well as optimizing existing therapies. AI is also used in personalized medicine. It uses an individual's genomic data and other types of health data to develop personalized treatment plans tailored to their specific needs, using machine learning algorithms to predict an individual's response to a particular treatment and identify potential adverse reactions. AI is also used in disease diagnosis and prediction. It is used to analyze data, such as electronic health records and wearable devices, to identify patterns and correlations that may indicate the presence of a particular disease, helping to improve diagnosis accuracy and enable earlier intervention to prevent disease progression. AI is used in the analysis of biomedical images. It is used for medical images, such as CT scans and MRI images, to identify abnormalities and diagnose diseases, using deep learning algorithms for automatic segmentation and classification of structures in medical images. The adoption of AI in pharmacological research raises ethical considerations. Ensuring data privacy and security, addressing bias and algorithm transparency, obtaining informed consent, and maintaining human oversight in decision-making are key ethical issues. Responsible AI application requires robust frameworks and regulations. The future of AI in pharmacological research is promising, with integration with new technologies such as genomics, proteomics, and metabolomics offering the potential for personalized medicine and targeted therapies. Collaboration between academia, industry, and regulatory bodies is essential for the ethical application of artificial intelligence in drug discovery and development. Continuous research and development of AI techniques and comprehensive training programs will

empower scientists and healthcare professionals to fully exploit the potential of artificial intelligence, leading to improved patient outcomes and innovative pharmacological interventions (Singh et al., 2023).

ARTIFICIAL INTELLIGENCE (AI) IN AGRICULTURAL BIOTECHNOLOGY

Facial recognition, predicting cancer in tissues, and metabolic flux analysis are just a few examples of significant advancements achieved with AI approaches, and there is potential for a similar revolution in agriculture. According to a report published by the Food and Agriculture Organization (FAO) of the United Nations, the global population will reach over 9 billion by 2050. This demographic growth will ultimately pressure the agricultural sector's ability to provide sufficient food for the human population. To feed the growing global population and enhance the national economy, agriculture is a strategic sector. It is a significant source of income for many countries worldwide (Popović et al., 2010; 2011; 2012; 2013; 2014; 2016; 2018; 2020; 2021; 2022; Bošković et al., 2023a; 2023b; 2023c; 2023d). Agriculture occupies about 38% of the total land area of the planet. Most agricultural activities are now manual, and agriculture can greatly benefit from automation in terms of yield and resource input. Implementing technological discoveries in agriculture can contribute to changing rural economies and the livelihoods of agricultural producers. Agricultural techniques are generally designed to overcome various obstacles, including pest pandemics, inefficient pesticide and fertilizer use, weeds, drought, and lack of adequate irrigation systems, inefficient harvesting, storage, and ultimately marketing. The agricultural sector could be transformed by AI intervention in areas such as land management, water needs assessment, precise mapping of fertilizer, pesticide, insecticide, and herbicide needs, yield prediction, and overall crop management. With advancements in AI-based technology, drones and robots are used to improve real-time crop monitoring, harvesting, and subsequent processing. Biotech companies are currently using AI and ML techniques to design and train autonomous robots capable of performing

key agricultural activities such as crop harvesting much faster than traditional methods. Data collected by drones are processed and evaluated using deep learning and computer vision techniques. Machine learning approaches help access and predict a wide range of environmental variables that affect agricultural production, such as weather fluctuations and meteorological disasters in certain world regions. As mentioned, AI-based solutions in the agricultural industry help improve efficiency and control numerous aspects, such as crop yield, soil profile, crop irrigation, content detection, weeding, and crop monitoring (Popović et al., 2019; Stevanović et al., 2019; 2023; 2024).

Traditional and older examinations of morphological characteristics are time-consuming, prone to errors, and very expensive. Machine vision methods can be easily applied in agricultural practices to speed up and simplify procedures while improving precision and accuracy. Identifying and selecting improved hybrids and varieties can accelerate and facilitate the process using automated, non-invasive, rapid evaluation of various plant characteristics through high-throughput phenotyping methods. Thanks to AI tools, intelligent bundles and drone technology can now be used for several agricultural activities (Ljubičić et al., 2023). Recent developments in AI-based DU and ML algorithm design for agricultural product price estimation can enable farmers to achieve higher profits for their work and investment.

The Internet of Things (IoT) is used to provide easier living, safety, increased productivity, monitoring, and resource optimization in various industries. Agriculture is one of them, where IoT and robots are used before and after the cultivation process, from preparing the land for cultivation to supplying the consumer market. These domains include crop monitoring, smart irrigation, pest monitoring, smart pest control, harvesting, and safe supply to the consumer market while maintaining the quality and integrity of the final product. Thus, new automated methods have been introduced. These new methods have met food needs and enabled the employment of billions of people. Artificial intelligence has brought a revolution in agriculture. This technology has protected crop yields

from various factors such as climate change, population growth, employment issues, and food security problems (Kumar et al., 2022).

For efficient irrigation, artificial neural networks, fuzzy logic, and metaheuristic algorithms have recently been developed. According to a recent study, a convolutional neural network (CNN), which considers several environmental variables, is one of the most reliable ML algorithms for estimating soybean and maize yields. Recent advances in AI-based biosensors for early disease detection in plants, even in asymptomatic plants, have the potential to greatly minimize product loss caused by biotic stresses. AI-based drone technologies, such as EfficientNetV2, designed to detect and classify plant diseases with accuracy and precision of 99.99% and 99.63%, respectively, are among the promising automated technologies for monitoring plant health in a time-saving and cost-effective way. To detect bacterial leaf spots in cultivated crops, an AI hybrid model based on convolutional autoencoder (CAE) and CNN achieved 99.35% and 99.38% in training and testing periods (Bhardwaj et al., 2022).

Due to his initial observations and conceptualization of smart machines, Alan Turing is considered the father of artificial intelligence and modern computer science. He was an early advocate of the theory that the human brain essentially functions as a digital computer (Akman and Blackburn, 2000). He pioneered the experiment known as the "Turing Test," which became a key moment in AI development. His work, titled "Computing Machinery and Intelligence," dealt with the possibility of a non-living computer thinking like a human and was a landmark in this field (Turing, 1950). Several other significant events paved the way for the development of the AI we see today (Figure 3, Bhardwaj et al., 2022). The use of AI can facilitate the identification of potential targets in large genomic data sets for genetic manipulation and design efficient synthetic promoters to improve plant agronomic traits. Increasing needs for smart agriculture have led to significant advancements in AI-based agricultural prediction and forecasting, greatly improving crop productivity. A similar attempt was made in a recent study where image data sets were analyzed using AI algorithms, namely ANN and

genetic algorithm (GA)-based platforms, to predict crop yields in an optimized way.

Figure 3. Timeline of Artificial Intelligence development

During the training period, the model achieved a maximum validation accuracy of 98.19%, while a maximum accuracy of 97.75% was achieved during the testing period. This model worked efficiently with limited resources and less data, providing optimal results. In another significant study, a new methodology was proposed for predicting agricultural yield in greenhouse crops using recurrent neural network (RNN) and temporal convolutional network (TCN) algorithms. Based on previous environmental and production data, this approach can be used to more accurately estimate greenhouse crop yields than standard ML and DL methods. This experimental research also highlighted the key importance of previous yield data sets in accurately predicting future crop productivity. Several million individuals in developing countries benefited from the Green Revolution by preventing and combining high-yield crops, synthetic fertilizers, and water. However, due to the widespread misuse of herbicides, pesticides, and fertilizers, the Green Revolution cannot be considered entirely "green." Certain high-yield crop approaches typically require large amounts of agrochemicals and water. AI-based approaches are being developed to reduce reliance on harmful agrochemicals and achieve sustainability in agriculture. For optimizing agricultural resources, a remote sensing management system (RSCS)

has been developed. This methodology uses AI and ML technology to improve ecological sustainability while encouraging the planning of new agricultural products. When analyzed with other techniques, the findings revealed that RSCS demonstrated the highest accuracy, performance, data transfer speed, productivity, irrigation management, and carbon dioxide release ratio. AI models have the potential to manage agricultural products and productivity in a "green" way. In another study, a smart sprayer based on AI and machine vision was developed to spray herbicides specifically on certain weeds, thereby reducing excessive herbicide use for weed control and environmental pollution. This sophisticated technology combines state-of-the-art weed detection concepts, a unique fast and precise spraying method, and a weed mapping model with 71% and 78% precision and recall. Due to limited data collection techniques and the lack of integration of various data sources, data collection from agricultural regions related to soil hydration, crop quality, or insect infestation often depends on manual analysis (Bhardwaj et al., 2022). As mentioned, AI-based solutions in the agricultural industry help improve efficiency and control numerous aspects such as crop yields, soil profiles, crop irrigation, content detection, weeding, and crop monitoring (Talaviya et al., 2020; Kim, Gilley 2008), Figure 4.

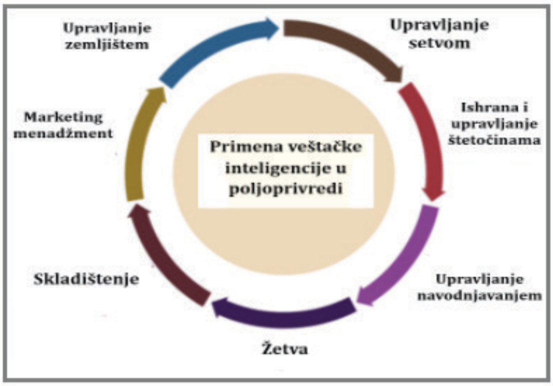

Figure 4. Areas in agriculture where Artificial Intelligence (AI) has a positive impact

Sophisticated AI models reduce the need for agrochemicals. In this regard, the significant NaLamKI action plan, which aims to develop open AI-based

software that could significantly assist the agricultural industry, received financial support from the German government. This plan seeks to develop data sets by combining information from various sensors to optimize different agricultural practices using AI and ML technologies. Similar government initiatives are needed in large numbers to help agricultural producers adapt to artificial intelligence on a larger scale.

In agriculture, integrating precise characteristics based on omics technology data can help identify critical traits involved in stress tolerance and acclimatization mechanisms, as well as contribute to the development of climate-resistant crops. Farmers will be able to generate more production with fewer resources, increase the quality of their production, and ensure faster market time for their harvested crops thanks to the adaptation of AI-based technology. While first-generation AI can be used in omics data research and classification, it is designed to handle specific issues related to single omics data sets without integrating data from other modalities. In agricultural biotechnology, next-generation AI is essentially envisioned to dynamically improve and process large multi-omics data sets in addition to predicting the cultivation values of complex traits under various environmental conditions (Harfouche et al., 2019).

ARTIFICIAL INTELLIGENCE (AI) AND INDUSTRIAL BIOTECHNOLOGY

Industrial biotechnology, known as white biotechnology, is the modern application of biotechnology for the sustainable processing and production of goods, chemicals, and fuels from renewable sources using living cells and their enzymes. The demand for industrial chemicals, pharmaceuticals, food chemicals, and other biochemistry-related raw materials has dramatically increased over the past decade. Machine learning (ML) and AI-based technologies can help design new pharmaceutical products and identify their efficacy and adverse effects before actual production, significantly reducing the time needed to bring drugs from the laboratory to the market for humans. Microorganisms and plant/animal cells are used in biotechnological processing to produce products in various

sectors, including drugs, pharmaceuticals, food, animal feed, disinfectants, cellulose, and textiles. To detect disruptions, optimize machines for efficient production, and improve product quality, the Internet of Things (IoT), ML, and AI can be effectively used. AI-based computer models are becoming increasingly widespread, and robotics and machine learning can be used to develop the best optimal conditions for strain growth and the extent to which valuable products can be obtained. For example, AI-based approaches or response surface methodology (RSM) have been used in the high production of amylase from *Rhizopus microsporus*, using various agro-industrial wastes for optimal experimental designs. Similarly, AI algorithms such as artificial neural networks (ANN) and genetic algorithms (GA) have been integrated to optimize fermentation media for *glucansucrase* production from *Leuconostoc dextranicum*. The integrated ANN-GA model predicted a 6% increase in glucansucrase activity compared to a regression-based prediction approach. The application of the integrated ANN-GA model for optimizing cellulase production from Trichoderma stromaticum in solid-state fermentation has been noted, achieving a 31.58-fold increase in cellulase production after optimization with the AI model (Singh et al., 2008).

AI-based technologies have also been used to scale up and optimize bioprocesses for enzyme production on a pilot scale. In one study, a cost-effective method was conducted to scale up the synthesis of extracellular laccase from *Staphylococcus arlettae* using tea waste. RSM and ANN, along with GA, were two successive statistical methods used to increase enzyme production, resulting in a sixteen-fold increase in enzyme yield. Also, some phase-expert system-based visual intelligence models are capable of monitoring pilot-scale wastewater treatment plants. Biofuel is one of the most important bioproducts whose industrial production process can be improved using ML and AI for maximum efficiency. In the bioenergy sector, AI-based approaches are used to predict biomass properties, bioenergy end-use, and the bioenergy supply chain. An integrated ANN-Taguchi method model has been developed to predict and maximize biofuel production through torrefaction and pyrolysis. Optimization and design of experimental factors were carried out using the Taguchi method,

which led to achieving maximum biofuel yield, while ANN showed linear regression prediction for biofuels (Bhardwaj et al., 2022). Integrated ANN-GA models have been used in modeling and optimizing the methanolysis process of waste peanut shells for biofuel production. This demonstrates that the integrated ANN-GA model has better optimization potential than the RSM model alone. ML-based bioprocess models have been constructed using AI-based methods such as ANN, CNN, long short-term memory networks (LSTM), k-nearest neighbors (kNN), and random forests (RF) to predict carbohydrate accumulation in cyanobacteria biomass grown in wastewater for biofuel production. The best results for system dynamics approximation were achieved with 1D-CNN with a mean squared error of 0.0028. Textiles, new chemicals, and biodegradable biopolymer synthesis could benefit from similar processes. It can be used to assist in developing synthesis techniques for such biochemicals that produce the highest yield with the least amount of resources. Additionally, AI could help predict market demand for drugs or chemicals in real-time. AI and ML have also aided metabolite production. Systematic metabolic engineering is a process that helps quickly produce high-performance microbial strains for long-term chemical and mineral production. The increasing availability of large biological data, such as omics data, has resulted in the application of ML techniques at various stages of metabolic engineering systems, such as host strain selection, metabolic pathway reconstruction, metabolic flux optimization, and fermentation. Various machine learning algorithms, including deep learning, have facilitated the optimization of bioprocess parameters and the exploration of a larger metabolic space associated with the biosynthesis of the target bioproduct. This trend also influences biotech companies to adopt ML techniques more frequently in designing their production systems and platform technologies. In the brewing industry, artificial intelligence has shown promising potential to overcome fundamental shortcomings and enhance production through knowledge accumulation and automated control. In one study, AI models were constructed using aroma profiles and spectroscopic data obtained from commercial alcohol to assess beer quality and aroma traits. Intelligent models resulted in highly accurate predictions for six main

beer aromas. ANN model-based technologies have also been developed to assess the presence of various chemicals in beer, such as ethanol, methane, carbon monoxide, hydrogen sulfide, ammonia, and so on. The study involved developing a computer program that simulated the operation of a highly adaptable multilayer perceptron network, which could predict changes in white wine fermentation parameters using data from previous experiments. This study provided a convenient approach to digitizing the brewing process, allowing it to acclimate to other intelligent, knowledge-based frameworks. Another study led to the development of an innovative knowledge-based approach for controlling alcohol fermentation used in white wine production. The primary sources of information used in developing the AI model were various case studies and experimental results, as well as knowledge obtained from brewery experts regarding different parameters related to optimizing and controlling the overall process. Using software for monitoring, regulating, and collecting data from the fermentation bioreactor, an application for automated process control was developed (Gonzalez Viejo et al., 2019, Figure 5). More details about the robotic pourer and computer vision analysis can be found in the work of Gonzalez Viejo et al. (2016).

Figure 5. Equipment for assessing physical measurements of beer; video recorded for beer analysis using computer vision algorithms

Further incorporation of control systems, processes, and innovative advancements can be greatly facilitated by such AI models, thereby supporting sustainable development.

CHALLENGES AND LIMITATIONS OF USING ARTIFICIAL INTELLIGENCE (AI)

Despite its enormous potential, AI-based technologies have yet to enter everyday practice. AI models can enhance the accessibility of various biological sectors but can also exacerbate existing disparities. Since AI models rely heavily on the datasets on which they are developed, as well as the labels associated with them, biases towards underrepresented learning algorithms can be amplified. Several factors must be considered to properly assess the resilience of some deep neural networks. Metadata must be created, retrieved, and cleaned for model development. Programs should be further designed and evaluated under the supervision of field experts to analyze and correct inaccuracies made in practice. Despite significant advances in the design of AI and ML-based models in recent years, few have been integrated into healthcare, and many opportunities for adopting these models for everyday use remain untapped. CNNs, for example, were initially used in study designs starting in 2015, primarily on dental X-rays, and the first clinical uses of these tools only recently emerged. The unavailability of clinical data due to organizational policies, insufficient reproducibility in data set processing and outcome assessment, and ongoing concerns about accountability and transparency towards patients remain the most common barriers to adopting AI in routine medical and dental practice. Several models have been reported to be inaccurate in predicting clinical diagnoses. An AI algorithm has been developed to diagnose and classify chest X-rays using NLP for radiology records. These classifications were later used in training a deep learning network to detect abnormalities in images, with a particular focus on identifying pneumothorax. After a detailed review, the presence of chest tubes in most reports identified as pneumothorax raised the question that the algorithm was recognizing chest tubes instead of pneumothorax as intended

(Liong-Rung et al., 2022, 893208). Due to different marginalizations in training datasets, modeling sensitivity to genetic diseases is also predisposed to varying performances among different demographic groups.

Additionally, the amount of computing time required for ML approaches may vary depending on the data size. Using AI-based approaches will not always lead to improvised categorization or better prediction than current methods. AI is a tool that should be used in the appropriate context to address a relevant issue or solve a significant problem. Similarly, in other biological areas such as agriculture, automating practices using AI and machine learning approaches has great potential for sustainable agriculture. However, in the agricultural sector, data collection, analysis, and usage for productivity present numerous challenges. Data privacy and security are two major challenges that farmers must address to survive in the digital age. In most cases, they are not informed about data collection, usage, and, more importantly, the purposes for which their personal data are used. Data mining enables corporations to rely on individuals to collect massive amounts of agricultural data, which may be sufficient to develop and evaluate behavioral and psychiatric profiles of subjects. To prevent data misuse, agricultural producers require assurance that their information will be used to generate innovative ideas and agricultural solutions, not to gain a competitive advantage. As mentioned, AI-based drone technology has emerged as a very efficient approach in agriculture. However, drones, especially those equipped with high-resolution lenses, infrared cameras, competent programs, and sensors, are very expensive for small agricultural producers. To operate drones, authorization is required following their operational and regulatory provisions of land law. Also, weather has a huge impact on drone operations. Traditional data mining methodologies were primarily developed for relational datasets; however, they are not entirely adequate for geographically dispersed data. To develop agriculture with AI-based technologies, innovative data mining approaches are needed. In the industrial biotechnology sector, establishing defined and sustainable protocols for algorithm adoption and data set size assessment remains a significant challenge. Designing such protocols would require a

thorough knowledge of the effects/efficacy of different algorithms and training datasets to address numerous bioindustry challenges. Increased availability, good documentation, and superior data collection methods are still needed for the development, operation, and optimization of bioenergy systems and bioreactor design. In some AI models, when the input is inadequate, especially for large datasets, the algorithm may instruct each variable as a separate instance instead of learning the information, resulting in errors and lower training efficiency. Additionally, numerous systems represented by ANN are often penalized due to black-box characteristics. Nevertheless, the lack of comparative work in different AI-ML designs makes it challenging to present a clear direction for future studies or practical applications. Challenges still need to be overcome, including inefficient data integration arising from diverse datasets, including candidate data, metadata, processed data, raw data, and the lack of an appropriate set of skills and expertise related to the subject. In this context, it is essential to overcome these uncertainties using new AI algorithms to achieve fundamental compliance between expected outcomes and empirical studies (Holzinger et al., 2023, 24). Therefore, more comprehensive datasets and relative studies are needed to develop AI and ML-based models for real-time monitoring and control of bioreactors and bioprocesses.

CONCLUSION

One of the great achievements we have witnessed in the era of Industry 4.0 is the ability of machines to replicate the capacities of living systems, especially human intelligence. The potential of artificial intelligence could be harnessed in the biological world, including medical research, agriculture, and biology-based industries, for sustainable living. Early prediction and identification of diseases and their precise treatment based on personalized medicine, even when diseases are in asymptomatic states, are examples of key areas of medical science that could benefit from AI. This would save millions of lives and reduce medical costs. Besides the medical field, efficient AI-based algorithms and programs have recently been developed to provide efficient resources and results in

agriculture, a practice known as precision agriculture. Agricultural practices such as land management, water needs analysis, fertilizer needs modeling, pesticides, insecticides, herbicides, yield projection, and overall crop management can be revolutionized by AI intervention. This would meet the growing global demand for food. AI-based programs and computer models have proven to be very effective in optimizing suitable conditions for obtaining the maximum desired product, whether for agricultural, medical, biotechnological, or everyday use, with minimal costs. Efficient production of bioenzymes is just one such success, and it is easy to imagine how the biotechnology industry will be transformed by the application of artificial intelligence, which will help reduce production costs, one of the biggest challenges facing the industry today. Traditional medicine is used by 60% of the world's population and originates from medicinal plants from wild populations. AI is used in medicine in drug discovery and development: to identify patterns that help in identifying new drugs and drug targets, as well as to optimize existing therapies, then in personalized medicine, in disease diagnosis and prediction, in biomedical image analysis, to identify abnormalities and diagnose diseases, using deep learning algorithms for automatic segmentation and classification of structures in medical images.

More than 90% of technological innovations in human history occurred in the 20th century, and it is expected that 99% of innovations will happen in the 21st century. The reason for this is seen in the explosion of artificial intelligence in the middle of the century and the expected emergence of artificial superintelligence in the second half of the 21st century.

We cannot exclude the possibility that the artificial intelligence we have created, driven solely by its own interests, will one day turn against humans if we do not regulate its development in time and incorporate empathy and respect for humans and all living beings on the planet as mandatory elements of the system.

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REFERENCES

1. Akman, V., Blackburn, P. 2000. Editorial: Alan Turing and Artificial Intelligence. *J. Logic Lang. Inf.* 9:391–395. https://doi.org/10.1023/A:1008389623883.
2. Bhardwaj, A, Kishore, S, Pandey, D.K. 2022. Artificial Intelligence in Biological Sciences. *Life -Basel*. 12(9):1430. https://doi.org/10.3390/life12091430
3. Bošković, J., Popović, V., Mladenović, J., Stevanović, A., Ristić, V., Maksin, M., Jovanov, D. 2023a. The future of smart agricultural production through applied information technologies. *IRASA International Scientific Conference Science, Education, Technology and Innovation, SETI V, 14.10.2023, Belgrade*, p. 3-35.
4. Bošković, J., Mladenović, J., Popović, V., Stevanović, A., Ristić, V. 2023b. Significance of new plant breeding technologies for sustainable agriculture and food security. I*RASA International Scientific Conf. Science, Education, Technology and Innovation, SETI V, 14.10.2023. Belgrade*. p.150-180. ISBN 978-86-81512-11-1
5. Bošković, J., Mladenović, J., Ristić, V., Burić, M., Popović, V. 2023c. Genetic approach and explanation of intelligence. *IRASA Intern. Scientific Conf. Science, Education, Technology and Innovation, SETI V, 14.10.2023. Belgrade.* p.113-140.
6. Bošković, J., Mladenović, J., Popović, V., Ristić, V., Stevanović, A., Šarčević-Teodosijević, Lj. 2023d. Specific reactions of plants to abiotic stresses with physiological biochemical and molecular perspectives. I*RASA International Scientific Conference Science, Education, Technology and Innovation, SETI V 2023, 14.10.2023 Belgrade*. p. 369-389.
7. Chi, M., Huang, R.,George, J.F. 2020. Collaboration in demand-driven supply chain: Based on a perspective of governance and

IT-business strategic alignment. *International Journal of Information Management,* 52: 102062.

8. Collins, C., Dennehy, D., Conboy, K., Mikalef, P. 2021. Artificial intelligence in information systems research: A systematic literature review and research agenda. *International Journal of Information Management.* 60: 102383. https://doi.org/10.1016/j.ijinfomgt.2021.102383
9. Gonzalez-Viejo, C., Torrico, D.D., Dunshea, F.R., Fuentes, S. 2019. Development of Artificial Neural Network Models to Assess Beer Acceptability Based on Sensory Properties Using a Robotic Pourer: A Comparative Model Approach to Achieve an Artificial Intelligence System. *Beverages*. 5(2):33. https://doi.org/10.3390/beverages5020033
10. Gonzalez Viejo, C., Fuentes, S., Li, G., Collmann, R., Condé, B., Torrico, D. 2016. Development of a robotic pourer constructed with ubiquitous materials, open hardware and sensors to assess beer foam quality using computer vision and pattern recognition algorithms: RoboBEER. *Food Res. Int. 89*: 504–513.
11. Coombs, C. 2020. Will COVID-19 be the tipping point for the Intelligent Automation of work? A review of the debate and implications for research. *International Journal of Information Management,* 55: 102182.
12. Ghaffar Nia, N., Kaplanoglu, E., Nasab, A. 2023. Evaluation of artificial intelligence techniques in disease diagnosis and prediction. *Discov Artif Intell.* 3(1): 5. https://doi.org/10.1007/s44163-023-00049-5.
13. Duan, Y., Edwards, J.S., Dwivedi, Y.K. 2019. Artificial intelligence for decision making in the era of Big Data – evolution, challenges and research agenda. *International Journal of Information Management*, 48: 63-71.
14. Dwivedi, Y.K., Hughes, L., Ismagilova, E., Aarts, G., Coombs, C., Crick, T., Medaglia, R. 2021. Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, 57: 101994.

15. Harfouche, A.L., Jacobson, D.A., Kainer, D., Romero, J.C., Harfouche, A.H., Scarascia Mugnozza, G., Moshelion, M., Tuskan, G.A., Keurentjes, J.J.B., Altman, A. 2019. Accelerating Climate Resilient Plant Breeding by Applying Next-Generation Artificial Intelligence. *Trends Biotechnol.* 37:1217–1235. doi: 10.1016/J.TIBTECH.2019.05.007.
16. Holzinger, A., Keiblinger,K., Holub, P., Zatloukal, K., Müller H. 2023. AI for life: Trends in artificial intelligence for biotechnology. *New Biotechnology*. 74: 16-24.
17. Kim, M., Gilley, J.E. 2008. Artificial Neural Network Estimation of Soil Erosion and Nutrient Concentrations in Runoff from Land Application Areas. *Comput. Electron. Agric.* 64:268–275. https://doi.org/10.1016/J.COMPAG.2008.05.021
18. Kumar, A., Singh, S.R., Yadav, M.C., Bhuj, B.D., Dhar, S., Pruthi, N.K., Kumar, R., Bajpai, V., Rizwan, M., Jyoti, K., Singh Thapa, R., Kumar, V., Kumar, H., Kumar Mishra, B., Kumar, V., Rajput, A., Singh, A., Kumar, R. 2022. Artificial Intelligence, Internet of Things (Iot) and Smart Agriculture for SustainableFarming: A Review. *Annals of Plant Sciences*. 11(11): 5512-5564. http://dx.doi.org/10.21746/aps.2022.11.11.6
19. Lam, T.Y.T., Cheung, M.F.K., Munro, Y.L., Lim, K.M., Shung, D., Sung, J.J.Y. 2022. Randomized Controlled Trials of Artificial Intelligence in Clinical Practice: Systematic Review. *J Med Internet Res.* 24(8):e37188. https://doi.org/10.2196/37188.
20. Liong-Rung,L., Hung-Wen, C., Ming-Yuan H., Shu-Tien, H., Ming-Feng T., Chia-Yu, C, Kuo-Song, C. 2022. Using Artificial Intelligence to Establish Chest X-Ray Image Recognition Model to Assist Crucial Diagnosis in Elder Patients With Dyspnea. Frontiers in Medicine 9:893208, DOI: 10.3389/fmed.2022.893208
21. Lugano, G. 2017. Virtual assistants and self-driving cars. *Warsaw: 2017 ITST* Proceedings.
22. Schwartz, R., Dodge, J., Smith, N., Etzioni, O. 2019. Green AI. Commun. *ACM*, 63 (12): 54-63.

23. Ljubičić, N., Popović, V., Kostić, M., Pajić, M., Buđen, M., Gligorević, K., Bižić, M., Crnojević, V. 2023. Multivariate Interaction Analysis of *Zea mays* L. Genotypes Growth Productivity in Different Environmental Conditions. *Plants.* 12 (11): 2165. https://doi.org/10.3390/plants12112165
24. Nissen, M.E., Sengupta, K. 2006. Incorporating software agents into supply chains: Experimental investigation with a procurement task. *MIS Quarterly,* 30 (1): 145-166.
25. Popović, V., Glamočlija, Đ., Malešević, M., Ikanović, J., Dražić, G., Spasić, M., Stanković, S. 2010.Genotype specificity in nitrogen nutrition of malting barley.*Genetika,*43(1):197-204.
26. Popović, V., Glamočlija, Đ., Malešević, M., Vidić, M., Tatić, M., Ikanović, J.,Jakšić, S., Spasić, M. 2011. Uticaj folijarne prihrane i tretiranja semena preparatom na bazi Co i Mo na prinos soje. *Zbornik Instituta PKB Agroekonomik,* 25(1-2):117-125.
27. Popović, V., Jaksić, S., Glamočlija, Đ., Đekić, V., Grahovac, N., Mickovski Stefanovic, V. 2012. Variability and correlations between soybean yield and quality components, *Romanian Agricultural Research*, 29:131-138.
28. Popović, V., Miladinović, J., Vidić, M., Mihailović, V., Ikanović, J., Đekić, V., Ilić, A. 2014. Genotype x environment interaction between yield and quality components of soybean [*Glycine max*]. *Agriculture and Forestry*. Podgorica, 60(2): 33-46.
29. Popović, V., Malesević, M., Miladinović, J., Marić, V., Zivanović, Lj. 2013. Effect of Agroecological Factors on Variations in Yield, Protein and Oil Contents in Soybean Grain. Romanian Agricultural Research, 30: 241-247.
30. Popović, V., Tatić, M., Sikora, V., Ikanovic, J., Drazic, G., Djukic, V., Mihailovic, B., Filipovic, V., Dozet, G., Jovanovic, Lj., Stevanovic, P. 2016. Variability of Yield and Chemical Composition in Soybean Genotypes Grown Under Different Agro-ecological Conditions of Serbia. *Romanian Agricultural Research*, 33: 29-39.

31. Popović, V., Kolarić, Lj., Živanović, Lj., Ikanović, J., Rajičić, V., Dozet, G., Stevanović, P. 2018. Influence of row spacing on NAR–Net Photosynthesis Productivity of *Glycine max* (L.) Merrill. *Agriculture&Forestry*, 64(1): 159-169. doi.org/10.17707/AgricultForest.64.1.18
32. Popović, V., Vučković, S., Jovović, Z., Ljubičić, N., Kostić, M., Rakaščan, N., Glamočlija-Mladenović, M., Ikanović, J. 2020. Genotype by year interaction effects on soybean morpho-productive traits and biogas production. *Genetika*, Belgrade, 52(3): 1055-1073. https://doi.org/10.2298/GENSR2003055P
33. Popović, M.V., Šarčević-Todosijević, Lj., Petrović, B., Ignjatov, M., Popović, B.D., Vukomanović, P., Milošević, D., Filipović, V. 2021. Economic Justification Application of Medicinal Plants in Cosmetic and Pharmacy for the Drugs Discovery. Chapter 3. Ed. Emerald M. Book Title: An Introduction to Medicinal Herbs. *NOVA Science publishers,* USA, p.63-106. p.1-365. https://doi.org/10.52305/TKAL3430
34. Popović, V., Burić, M., Mihailović, A., Aćimić-Remiković, M., Vukeljić, N., Batrićević, M., Petrović, B. 2022. Medicinal properties of buckwheat products and honey in compliance with food safety regulatory requirements. *Journal of Agricultural, Food and Envoronmental Science*s, 76, 3, 16-24.
35. Singh, A, Majumder, A, Goyal, A. 2008. Artificial intelligence based optimization of exocellular glucansucrase production from *Leuconostoc dextranicum* NRRL B-1146. *Bioresour Technol.* 99(17):8201-6. https://doi.org/10.1016/j.biortech.2008.03.038
36. Singh, S, Kumar, R, Payra, S, Singh, SK. 2023. Artificial Intelligence and Machine Learning in Pharmacological Research: Bridging the Gap Between Data and Drug Discovery. *Cureus.* 15(8):e44359. https://doi.org/10.7759/cureus.44359
37. Sipior, J.C. 2020. Considerations for development and use of AI in response to COVID-19. *International Journal of Information Management*, 55: 102170.

38. Stevanović, A., Šarčević Todosijević, Lj., Bošković, J., Popović, V., Živanović, Lj. 2019. Organska proizvodnja, genetički modifikovani organizmi i očuvanje biodiverziteta-vodeći izazovi u zaštiti životne sredine. *Naučni skup Održiva primarna poljoprivredna proizvodnja u Srbiji-stanje, mogućnosti, ograničenja i šanse. Bačka Topola*, pp.95-102.
39. Stevanović, A., Bošković, J., Popović, V. 2024. Implications of HAARP system on climate change and sustainable agriculture. *International Multidisciplinary ConferenceChallenges of Contemporary Higher Education*" - CCHE 20224, Kopaonik January 29th - February 2024. p. 563-570.
40. Stevanović, A., Stevanović, S., Jauković, M., Bošković, J., Popović, V., Ristić, V., Šarčević Todosijević, Lj. 2023. Modern organic agriculture in accordance with global GAP standard and HACCP system. *IRASA International Scientific Conference Science, Education, Technology and Innovation, SETI V 2023, 14.10.2023 Belgrade,* pp. 37.
41. Talaviya, T., Shah, D., Patel, N., Yagnik, H., Shah, M. 2020. Implementation of Artificial Intelligence in Agriculture for Optimisation of Irrigation and Application of Pesticides and Herbicides. *Artif. Intell. Agric.* 4:58–73. https://doi.org/10.1016/J.AIIA.2020.04.002.
42. Turing, A.M.I. 1950. Computing Machinery and Intelligence. *Mind.* 59:433–460. https://doi.org/10.1093/MIND/LIX.236.433.
43. Wilson, J., Daugherty, P.R. 2018. Collaborative Intelligence: Humans and AI Are Joining Forces. *Harvard Business Review.*
44. Von Krogh, G. 2018. Artificial intelligence in organizations: New opportunities for phenomenon-based theorizing. *Academy of Management Discoveries,* 4 (4): 404-409.
45. Wang, C., Savkin, A., Clout, R., Nguyen, H. 2015. An intelligent robotic hospital bed for safe transportation of critical neurosurgery patients along crowded hospital corridors. *IEEE Transactions on Neural Systems and*

Rehabilitation Engineering, 23 (5): 744-754. https://doi.org/10.1109/TNSRE.2014.2347377

46. Wu, X, Liu, X, Zhou, Y. 2022. Proceedings of 2021 chinese intelligent systems conference: review of unsupervised learning techniques in lecture notes in electrical engineering. *Singapore*.